R&D Plans for PHENIX Upgrades

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STAR Workshop on Future Physics and Detectors

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New Physics to be Addressed with an Upgraded PHENIX Detector

- Improved measurements of heavy flavor (c,b) production
- Jet studies and **g**-jet correlations
- Low mass dilepton pairs and vector mesons
- High p_T identified particles
- Rare processes

  Inclusive particle spectra and direct **g**s out to high p_T

  Drell-Yan continuum above the J/**Y**

  Upsilon spectroscopy - **U**(1S),**U**(2S),**U**(3S)

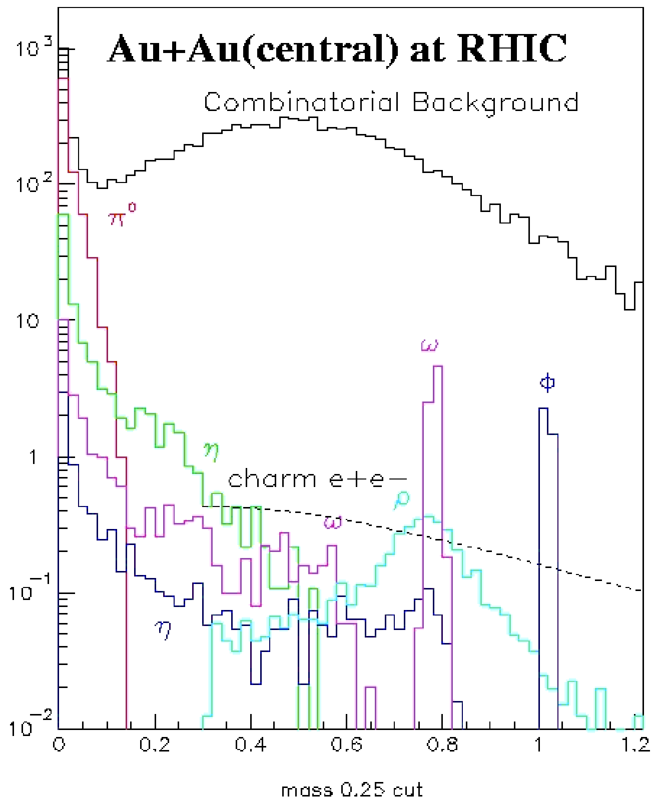
  W-production

  ...

Detector Requirements for New Physics

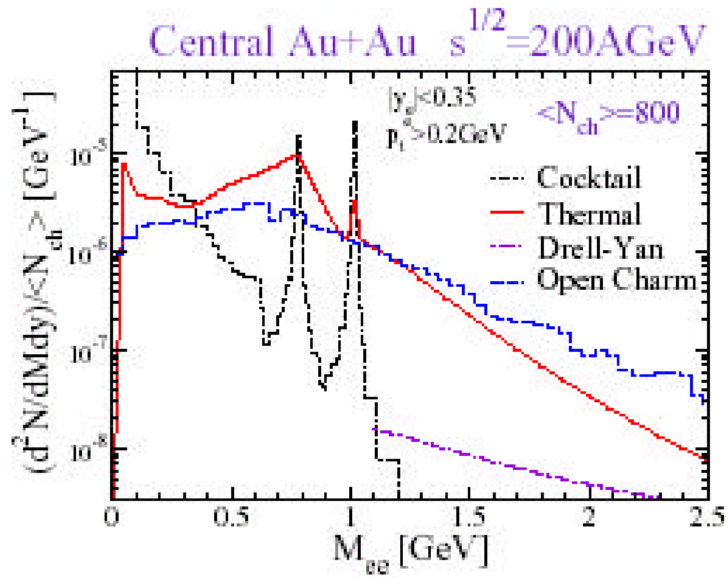
- Improved inner tracking detectors capable of directly measuring open charm and bottom decays by measuring displaced secondary verticies.
- Increased tracking coverage over 2π in azimuth and larger rapidity to measure jets and γ-jet correlations.
- Good rejection against Dalitz pairs and conversions, along with good electron efficiency down to low momentum, to measure low mass electron pairs and vector mesons.
- Good particle id out to high p_T
  - π/K/p separation to $p_T \sim 10$ GeV/c
  - electron identification to $p_T > 10$ GeV/c
- High rate data acquisition and triggering capabilities for studying rare processes.

Low Mass Electron Pairs at RHIC



Electron pair background in PHENIX

Y.Akiba

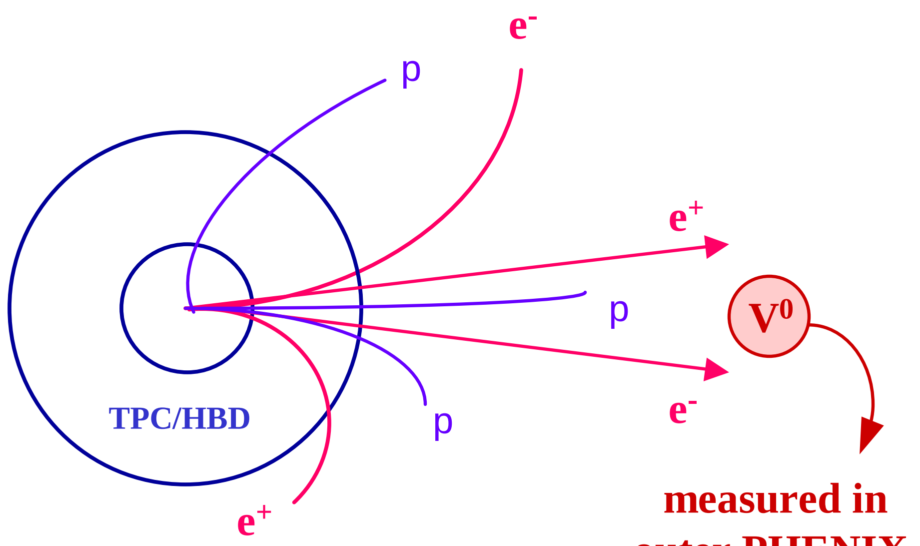


Dilepton spectra from central Au-Au collisions at full RHIC energy

R.Rapp

Strategy for Low Mass Pair Measurement

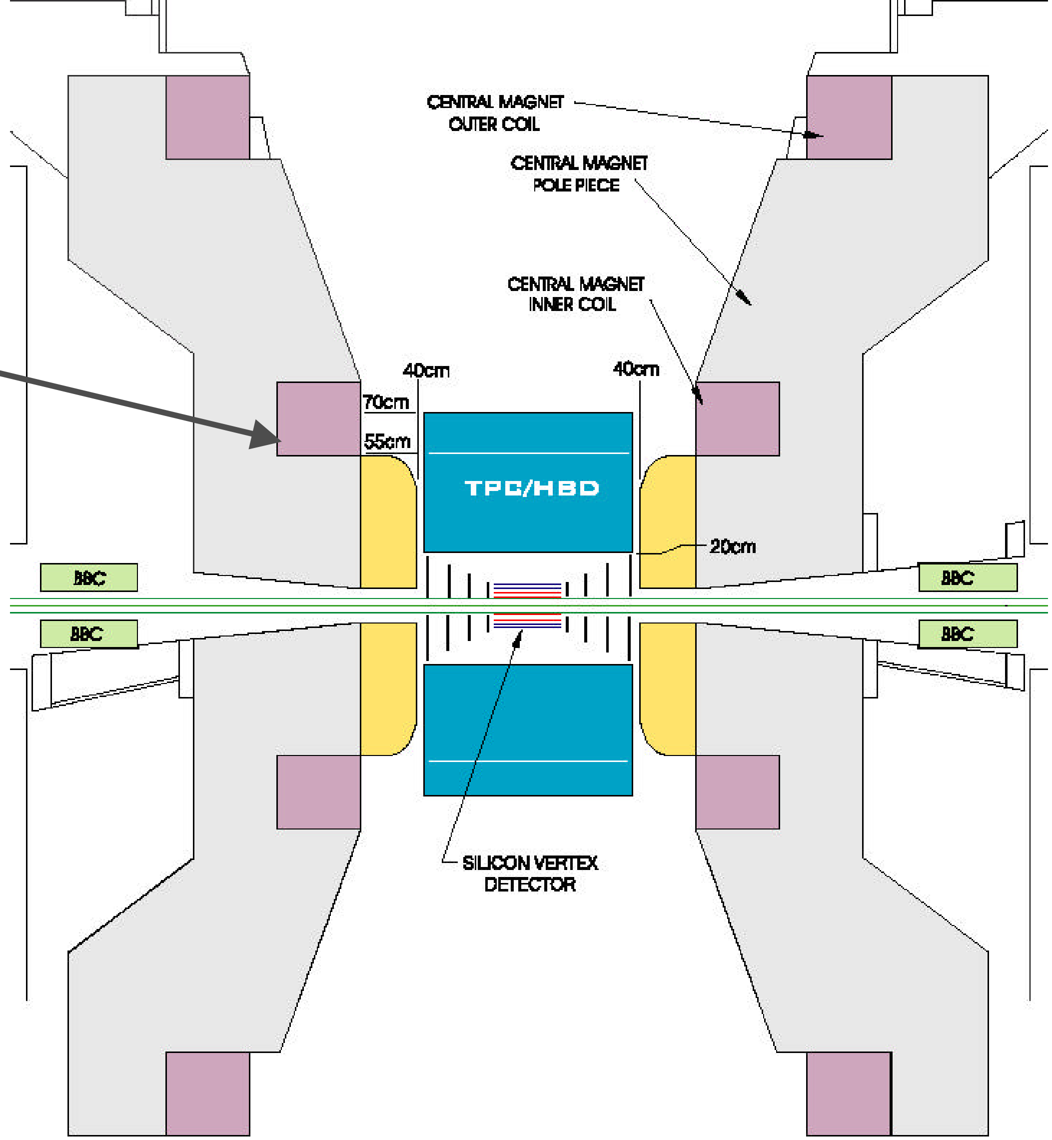
- **Operate PHENIX with low inner B field to optimize measurement of low momentum tracks**
- **Identify signal electrons (low mass pairs, ρ, ω, ϕ, …) with p>200 MeV in outer PHENIX detectors**
- **Identify low momentum electrons (p<200 MeV) using Cherenkov light from HBD and/or dE/dx from TPC**
- **Calculate effective mass (or opening angle) between all opposite sign tracks identified as electrons ($\varepsilon_{electron}$ > 0.9, π_{rej} > 1:200)**
- **Reject pair if mass < 130 MeV (or θ < 200 mrad)**



measured in outer PHENIX detectors (P_e > 200 MeV/c)

Must provide sufficient Dalitz rejection (>90%) while preserving the true signal

PHENIX Inner Detector



Inner Coil creates a "field free" ($\int Bdl=0$) region inside the Central Magnet

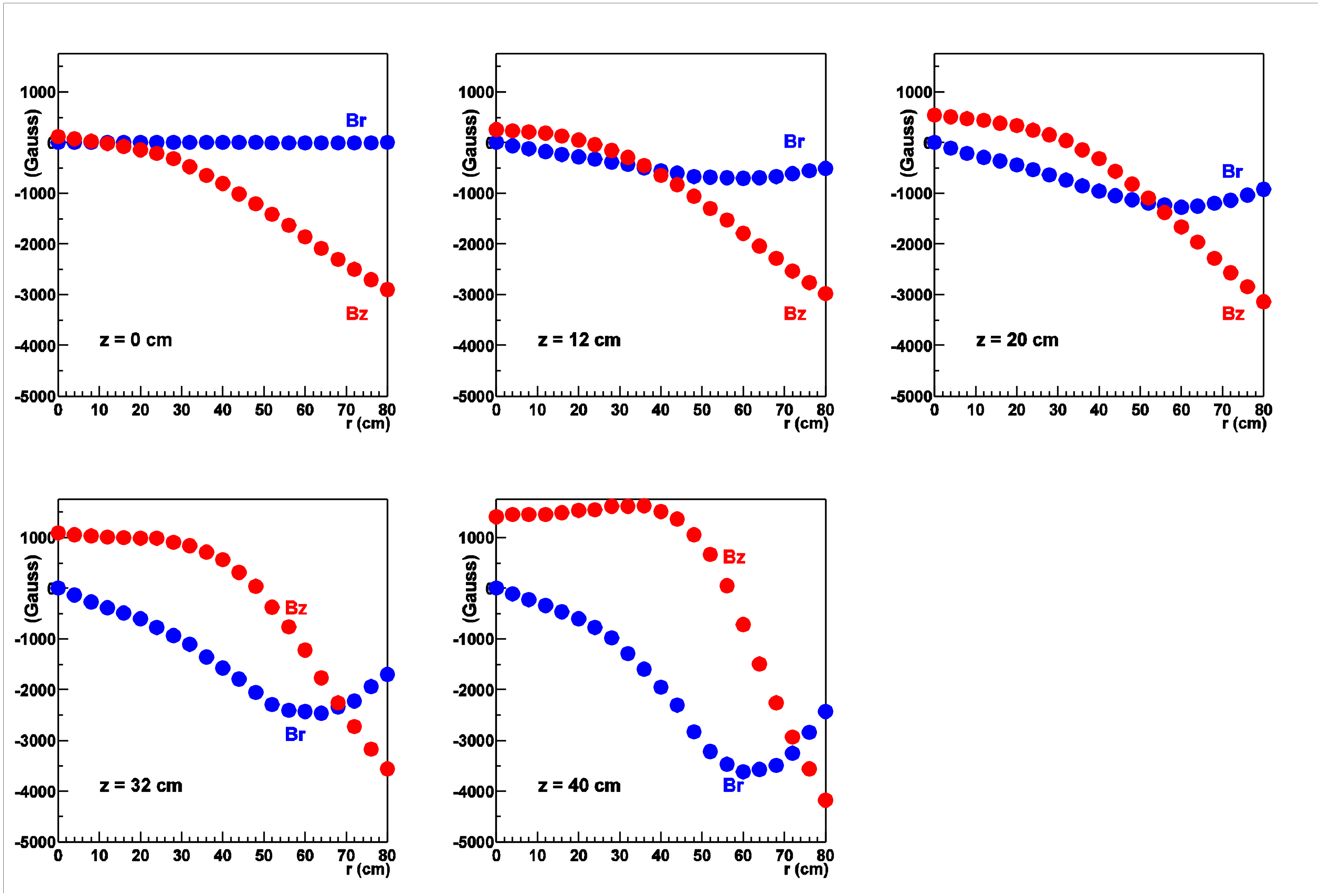
TPC tracking coverage

$\Delta\phi = 2\pi$

$-1.0<|\eta|<1.0$

$\delta p/p \sim 0.02p$

PHENIX Inner Field, ± Configuration

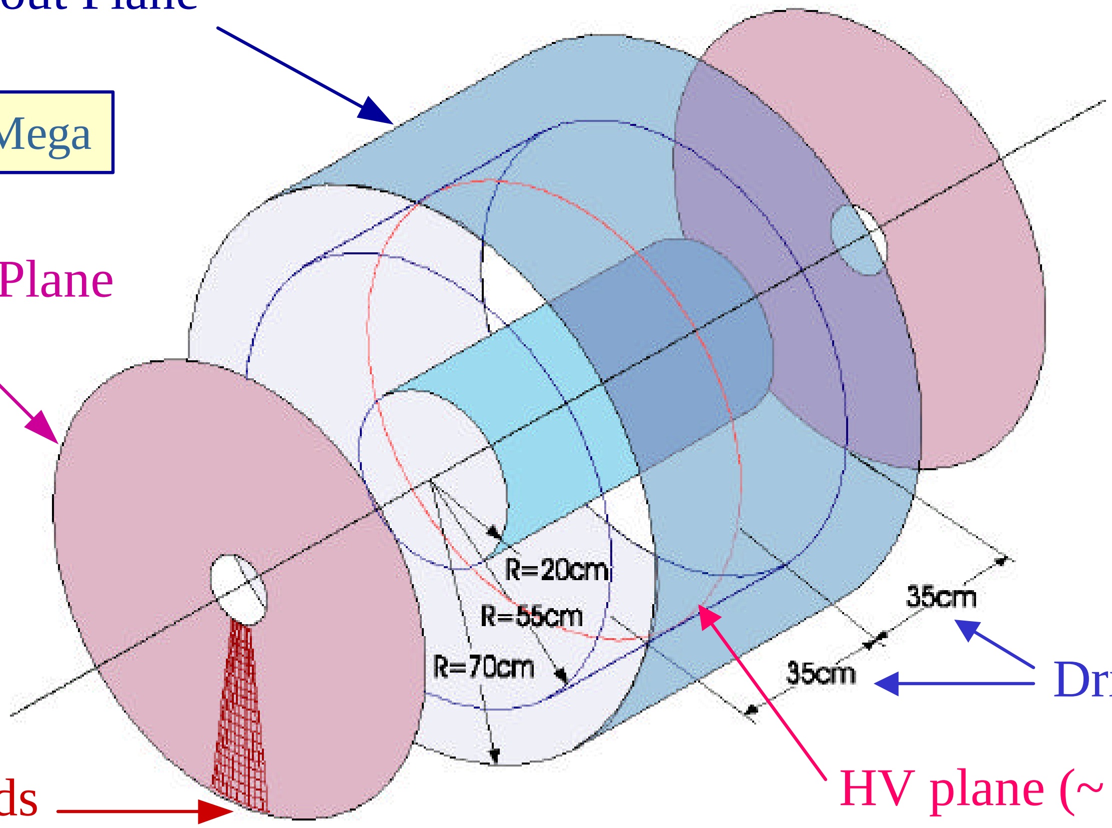


TPC/HBD Conceptual Design
(PHENIX + STAR)

CsI Readout Plane

GEM, μMega

TPC Readout Plane



Drift regions

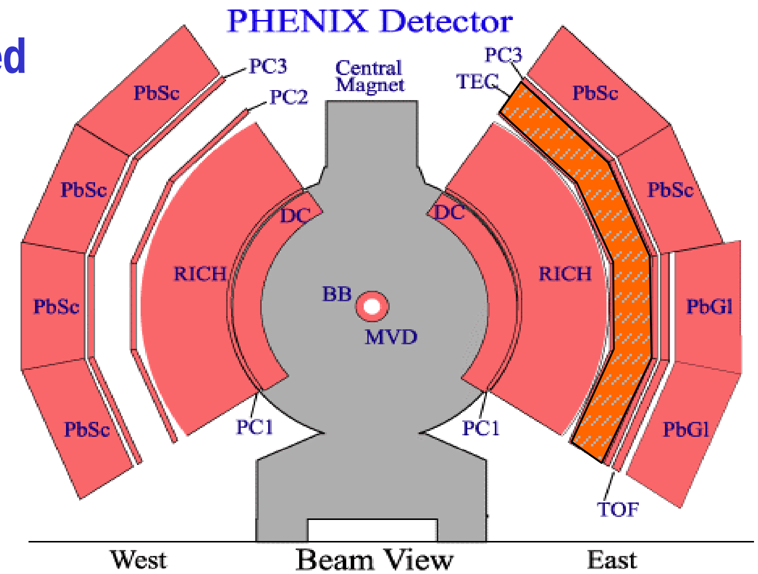
HV plane (~ -30kV)

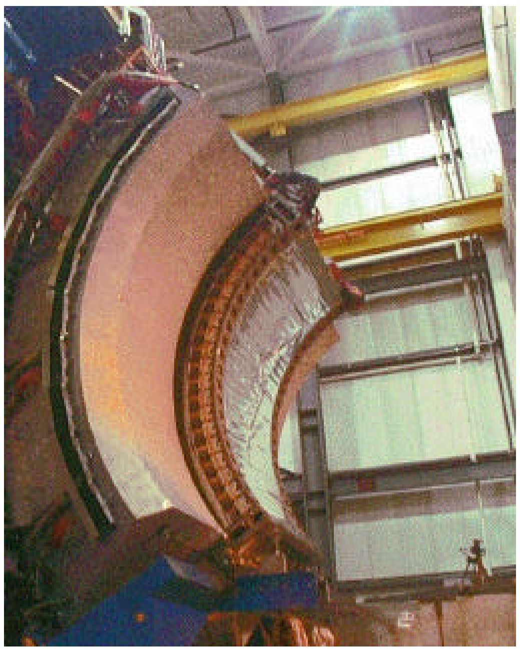
Readout Pads
$\Delta R \sim 1$ cm
$\phi \sim 2$ mm

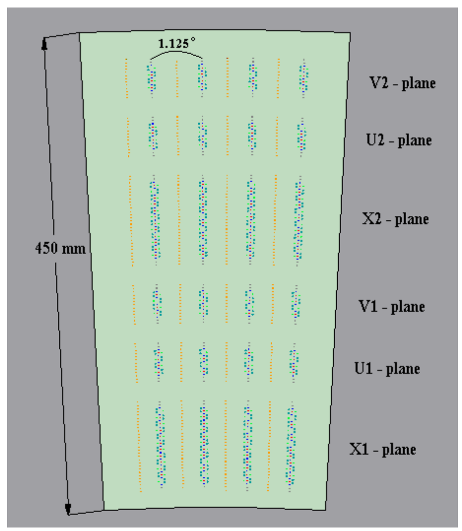
PHENIX Drift Chamber

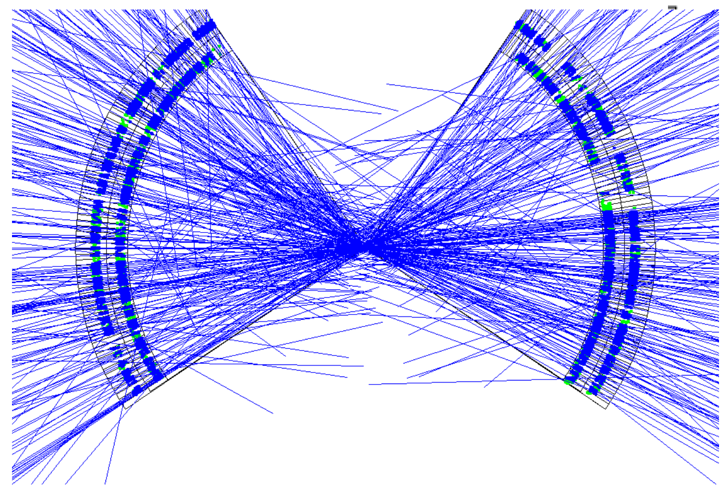
- **Jet -chamber anode/cathode structure modified for HI high multiplicity**
- ? $_x$ **= 120** ? **m , two-track sep = 2mm**
- d **p/p = 1.0% p + 0.8% (achieved)**

  0.3% p + 0.6% (design)





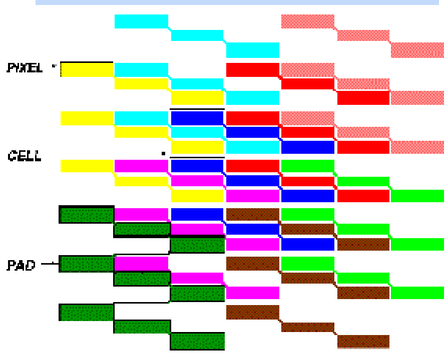


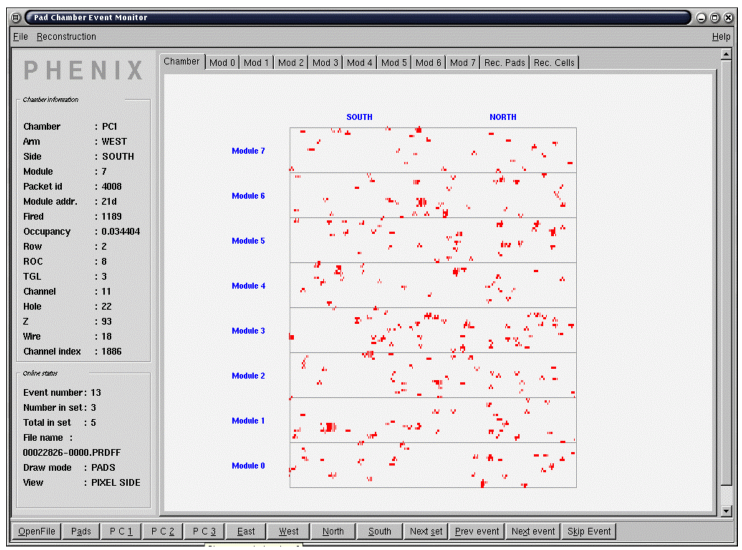


PHENIX Pad Chambers

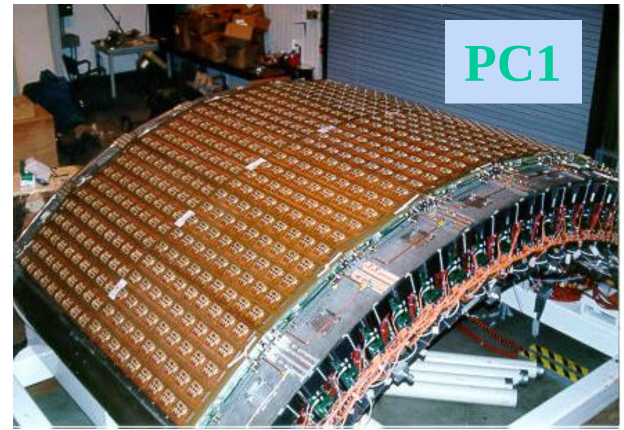
- Cathode wire chambers using fine granularity pixel pad readout
  - 2-D hit position, $?_x = ?_y \sim O(\text{mm})$
  - 173k channels total, ~ 100 m^2 detector coverage
- Low-mass , rigid honeycomb/circuit board construction
- All signal digitization takes place on-board in detector active region. Solves interconnect problem.

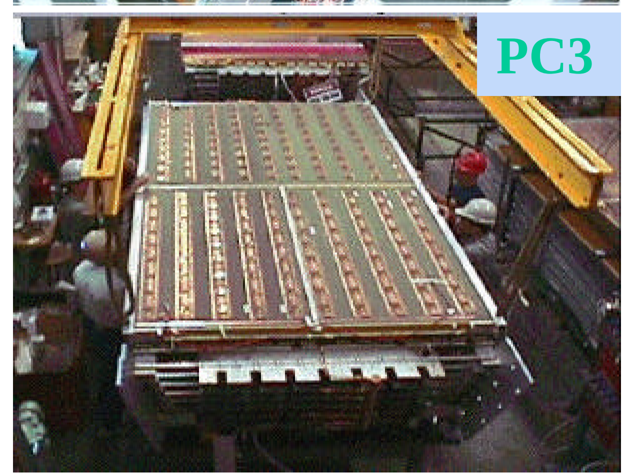
Pixel Pad Cathode Pattern





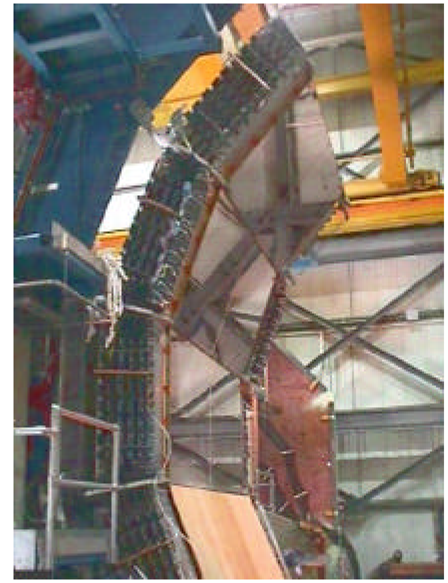
Clusters in PC from Central Au-Au collision



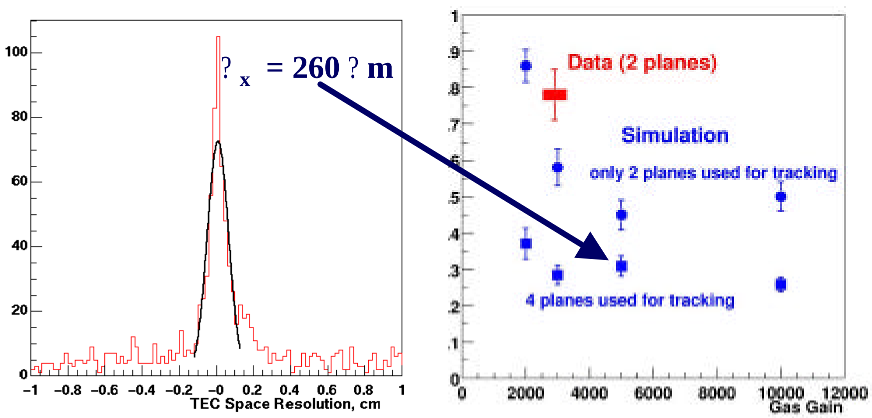


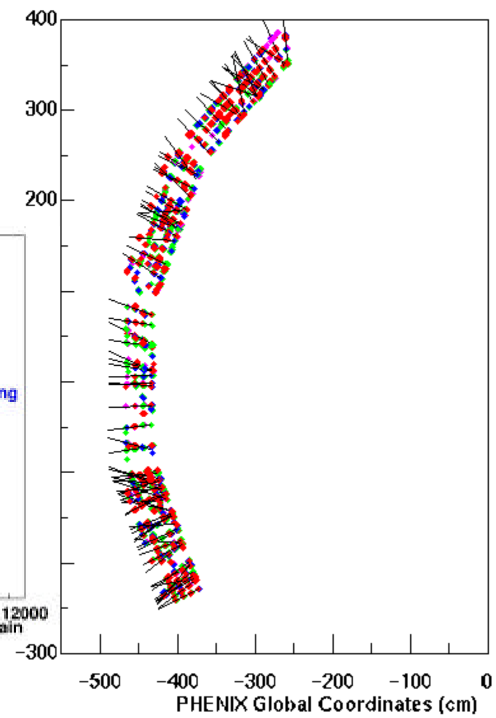
PHENIX Time Expansion Chamber

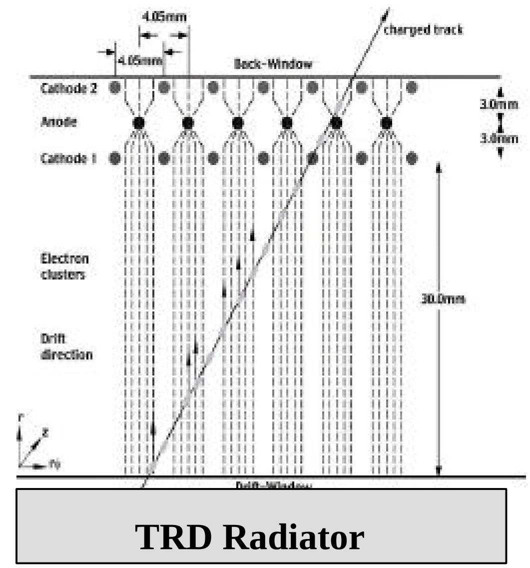
- **24 TEC Chambers arranged in 4, 6-Chamber sectors**
- **Used for tracking and PID (dE/dx,TR). ? $_x$ = 260 ? m**
- **dE/dx: e/p = 5% at 500 MeV/c (4 pls), e/p = 1.5% (6pls)
  Important for momentum resolution p_T > 4.0 GeV/c**
- **Designed for TRD Upgrade . High momentum e/p**



Tracks in TEC from Central Au-Au Collisions







TPC as an Inner Tracking Detector in PHENIX

- Expect $\delta p/p \sim 2\%$ (300 μm or better space points, ~35 pad layers)
- Would provide tracking resolution comparable with the silicon tracker over 2π in azimuth and $|\eta| < 1$
- Tracking through the central field (in normal running conditions) would give better rejection against false high p_T tracks
  - second independent momentum measurement
  - can observe decays, conversions, etc…
- Tracking through the highly non-uniform "field free region" would give better association of Cherenkov "blobs" with electrons in HBD
  - field would be optimized to measure low momentum tracks
  - could make effective mass cut rather than just opening angle cut
  - provides dE/dx information for e/π separation for $p < 200$ MeV/c

PHENIX Detector Upgrade R&D Program

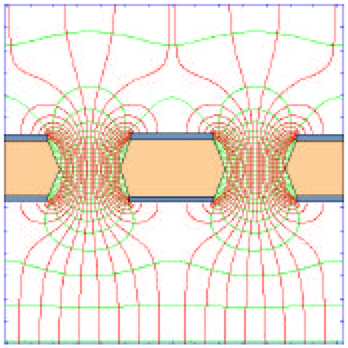
Follows the RHIC Detector Workshop (Nov 13-15, 2001)

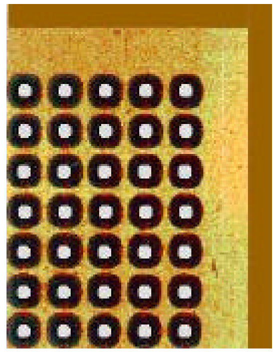
New technologies identified as required to meet the needs of the next generation RHIC experiments

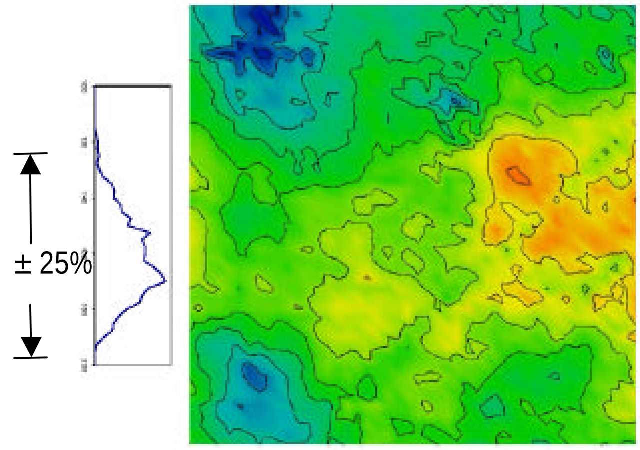
- Micropattern detectors (GEMs,**m**Megas)
- Study of fast drift gases with high UV transparency
- Study of large area photocathodes (CsI, CVD diamond)
- Development of high resolution silicon tracking detectors (Strips, Pads, Hybrid pixels, Active Pixel Sensors)
- Development of Aerogel cherenkov counters
- Development of highly integrated readout electronics
- Development and improvements of high rate DAQ systems

GEM Detector Studies

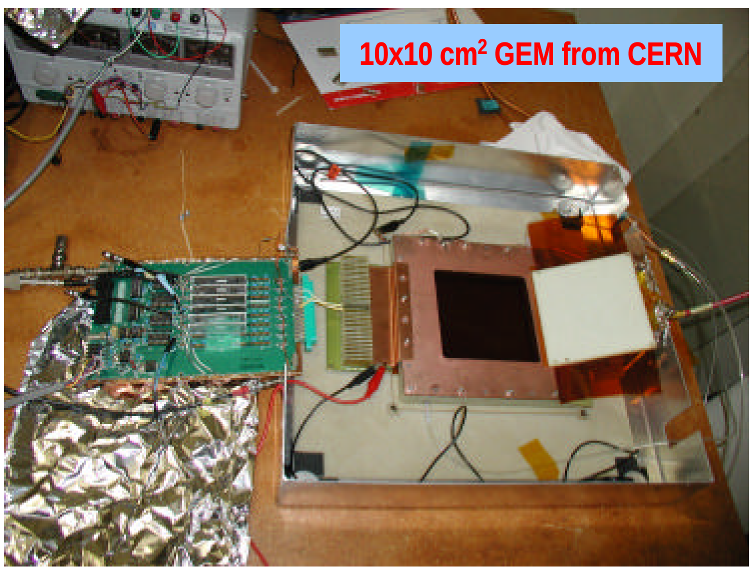
Gas Electron Multiplier

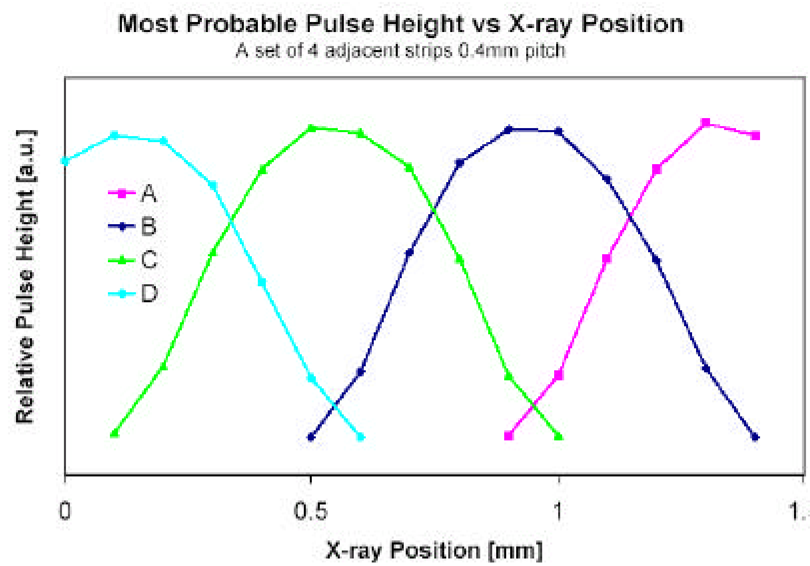




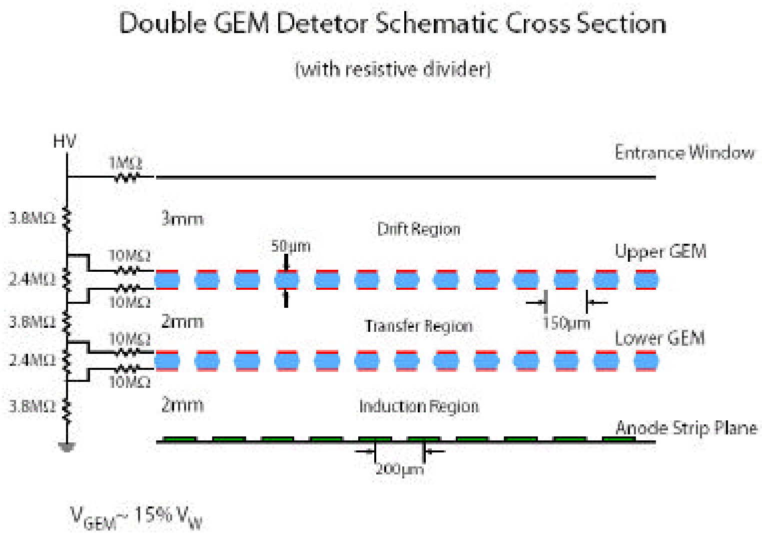


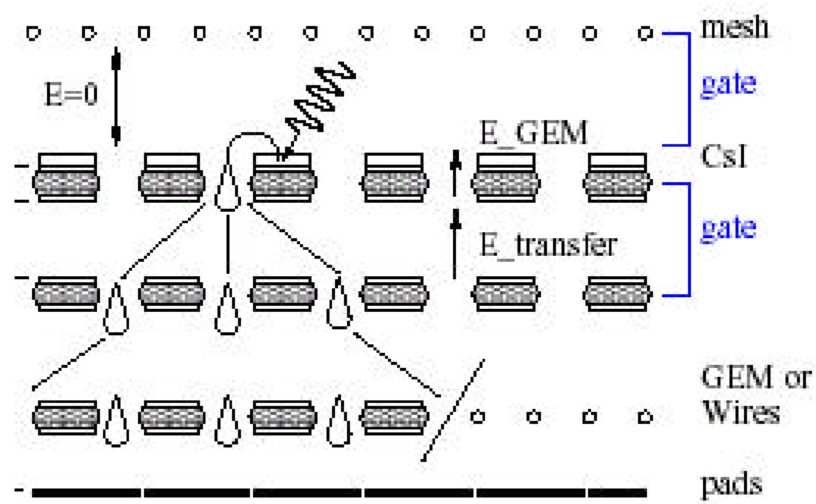
B.Yu





GEM Detector Issues



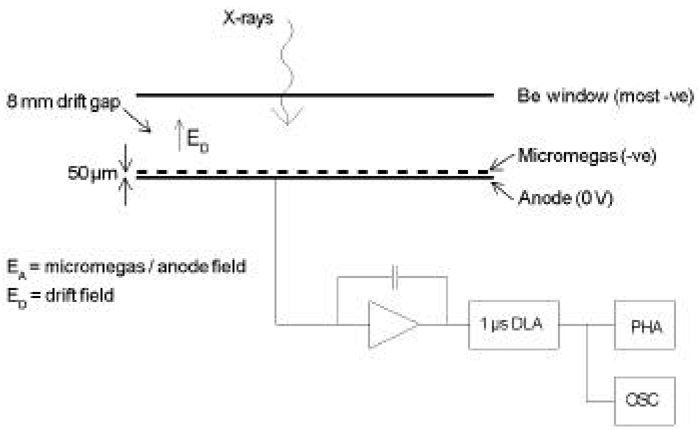


- GEM can give excellent position resolution (~ few hundred **m**m), butrequires large number of readout channels for TPC
- Needs to spread charge out on readout plane

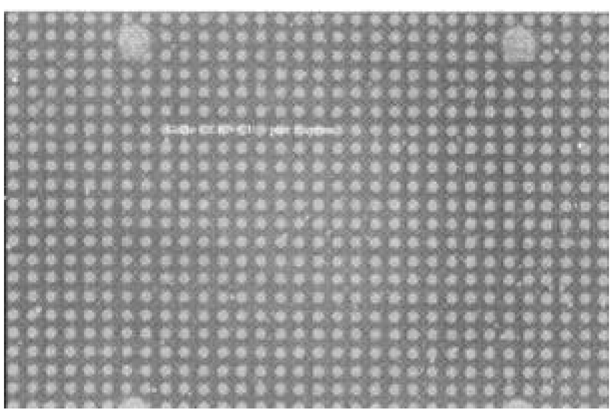
- CsI photocathode deposited on outer GEM foil
- Multistage GEM used to detect single photoelectons
- Is the HBD really “hadron blind”

MicroMega Detector Studies

MicroMega detector obtained from Saclay

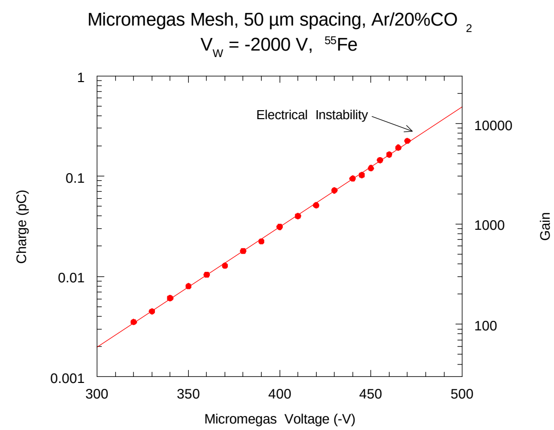


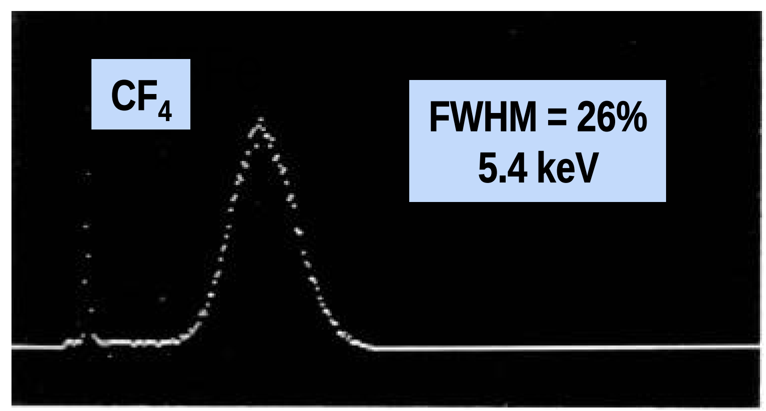
5 ?m copper, 25 ?m diameter holes, 50 ?m pitch



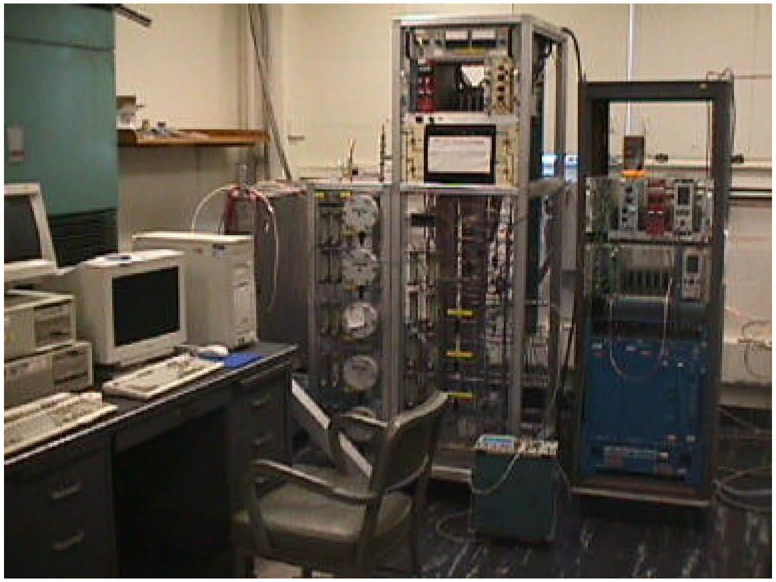
50 **m**m pillars spaced 2mm

G.Smith, B.Yu, I.Giomataris





Gas Detector Lab

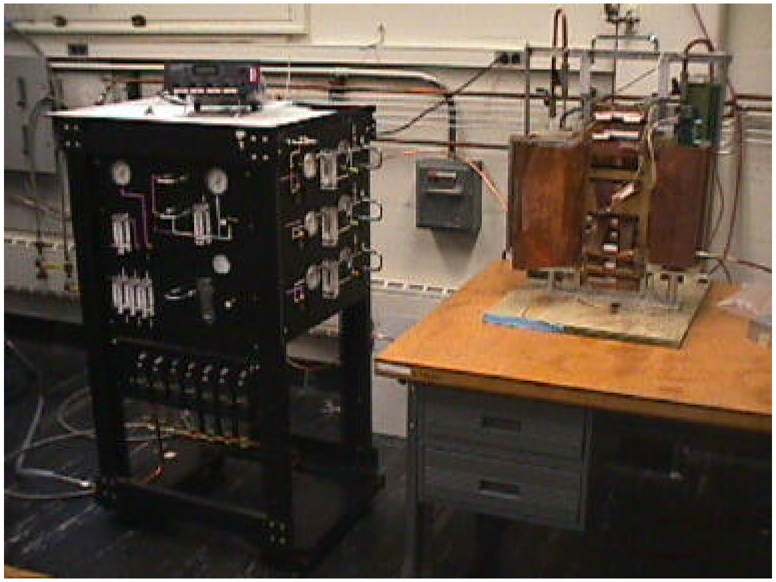


BNL
Physics 2-106

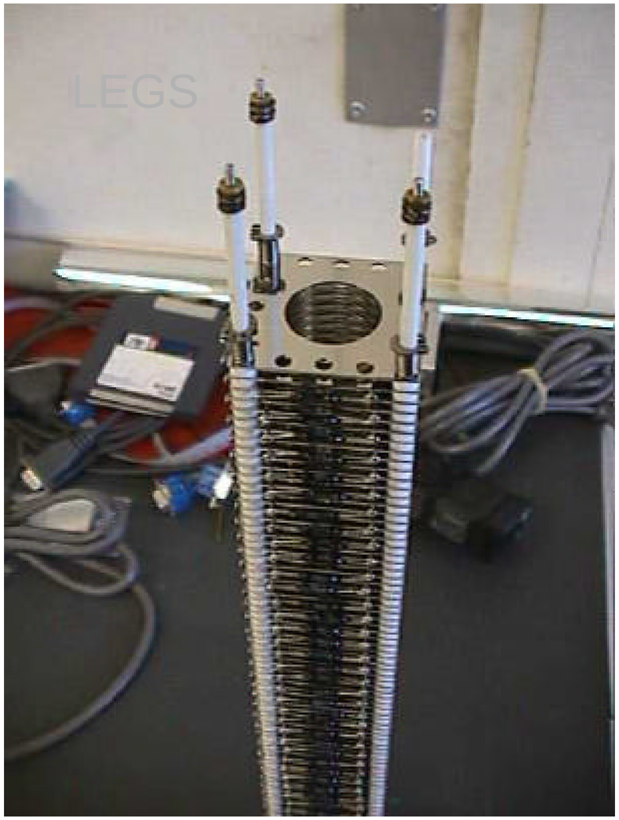
Reusing parts of the STAR TPC gas monitoring system

Measure drift properties of gases

- Drift velocities
- Drift lengths
- Diffusion parameters
- Ionization energy loss (dE/dx)
- Study impurities
- Study various types of readout detectors

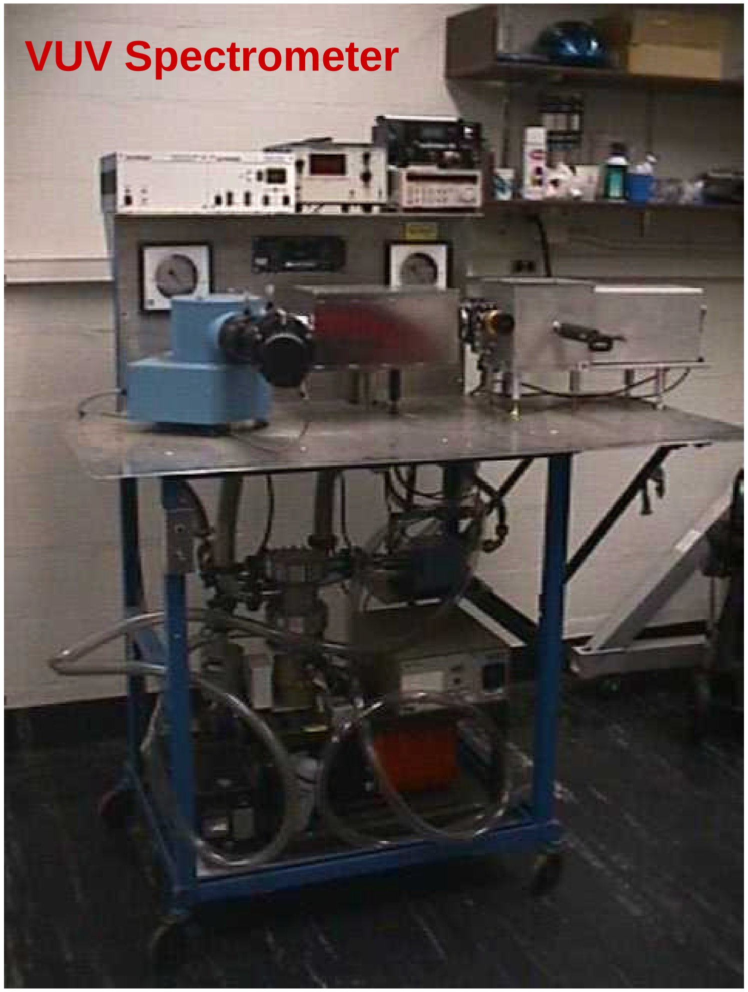


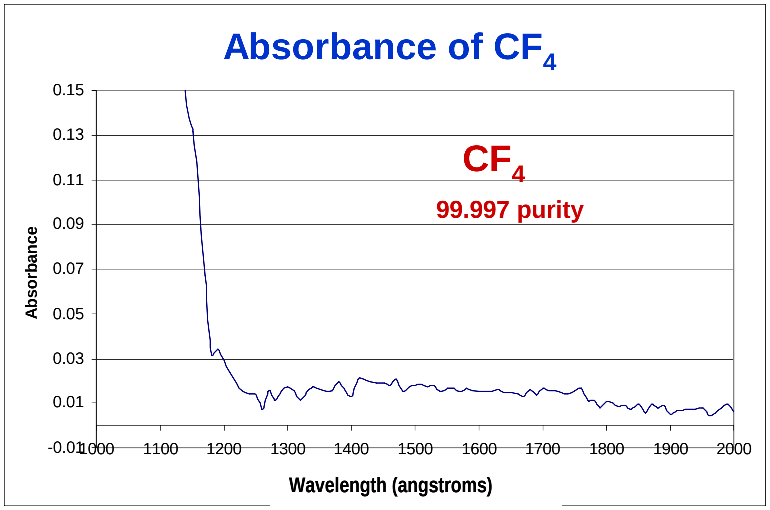
TPC Drift Cell

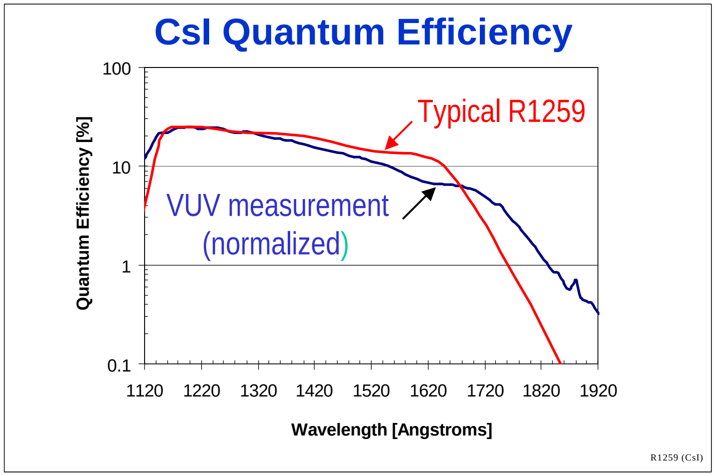


Constructing drift stack similar to one being tested for LEGS

Gas Transparency and Photocathode Studies in the VUV

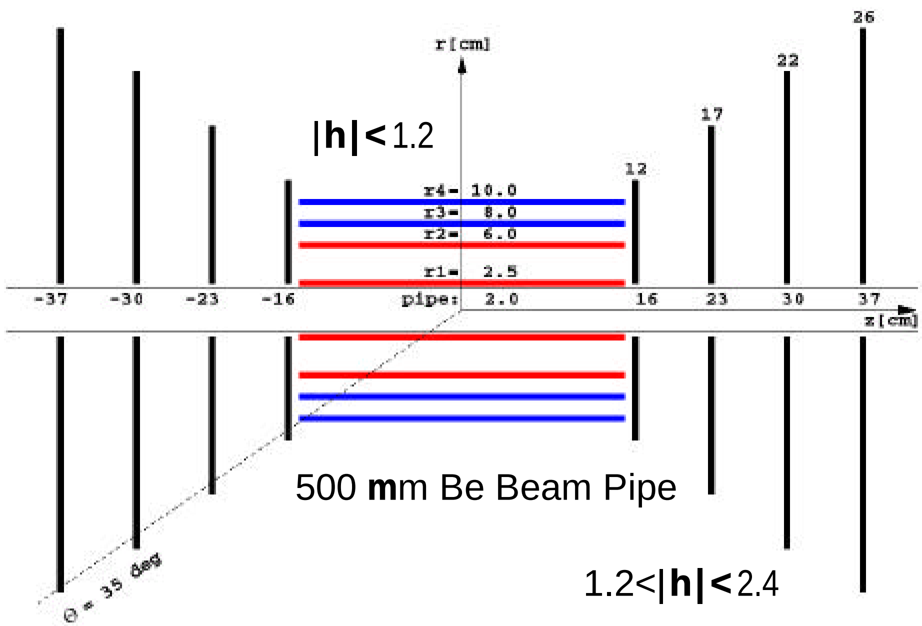






B.Azmoun

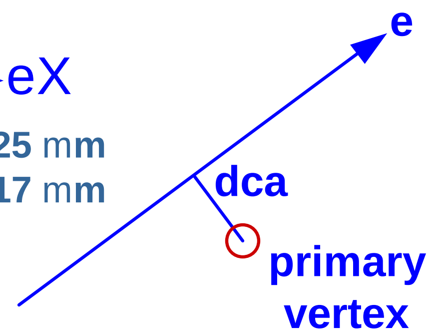
Proposed Silicon Tracker in PHENIX

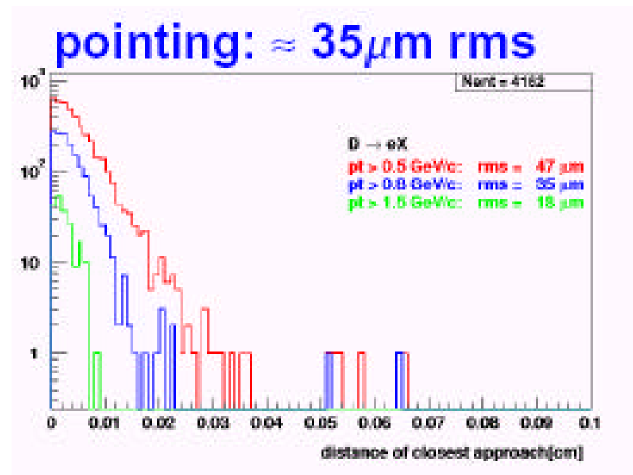


D→eX

c t $_0$ = 125 mm

c t $_\pm$ = 317 mm





Pixel barrels (50 mm x 425 mm)
Strip barrels (100 mm x 5 cm)
Pixel disks (50 mm x 200 mm)

1.0% X_0 per layer

Simulation by J. Heuser

Technology Choices for Silicon Detectors

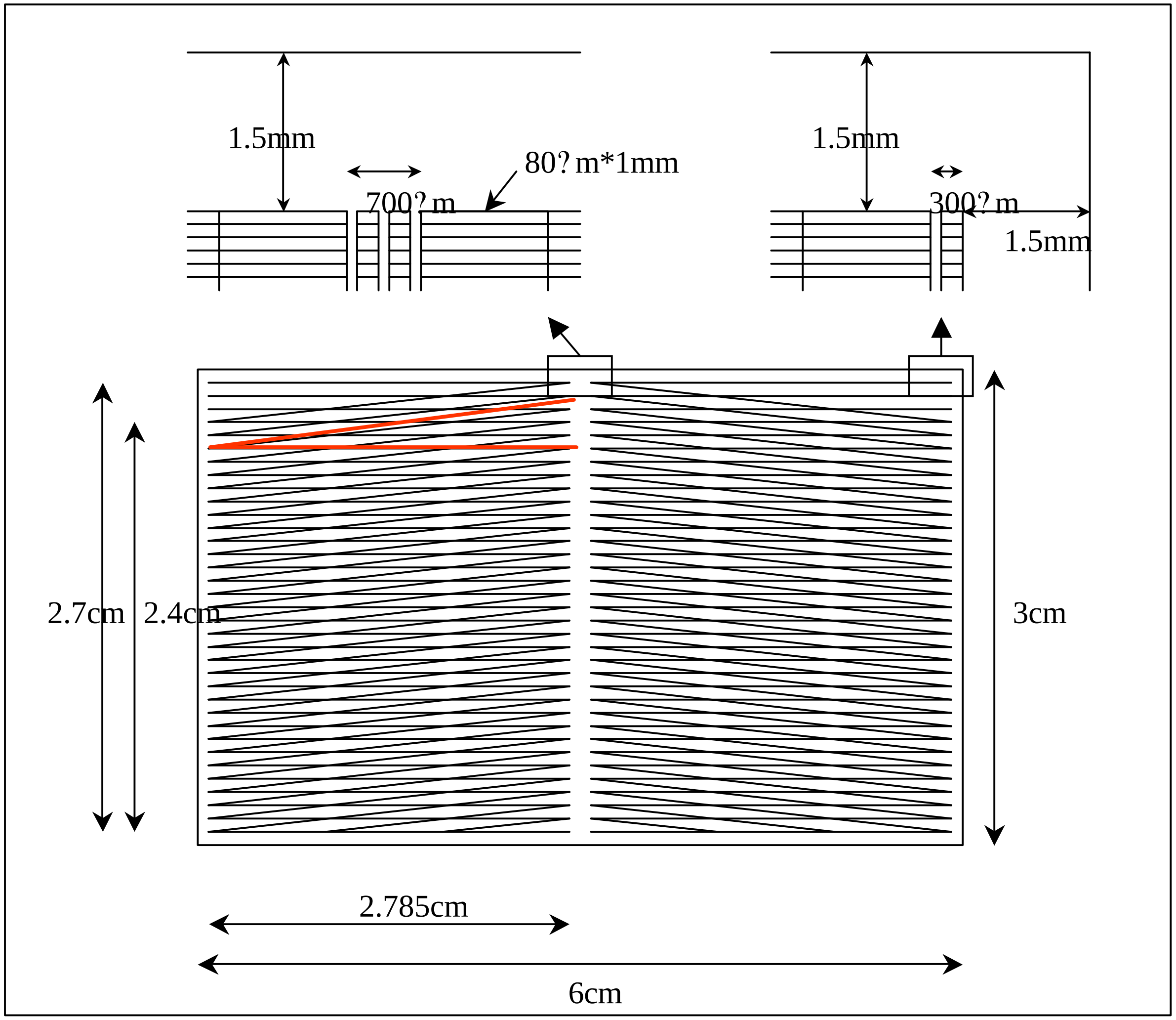
- **Silicon Strips**
  - Prototype development at BNL
  - readout electronic options
    - ABCD chip (ATLAS)
    - SVX4 chip (Fermilab)
    - AP6 (CMS)
    - …. .
- **Hybrid Silicon Pixel**
  - adapt ALICE (NA60) readout chip
  - R&D collaboration with NA60/ALICE
  - sensors for NA60 being developed at BNL
- **Monolithic active pixels**
  - LEPSI, LBL (STAR), Iowa State
  - longer time scale

Silicon Strip Detectors

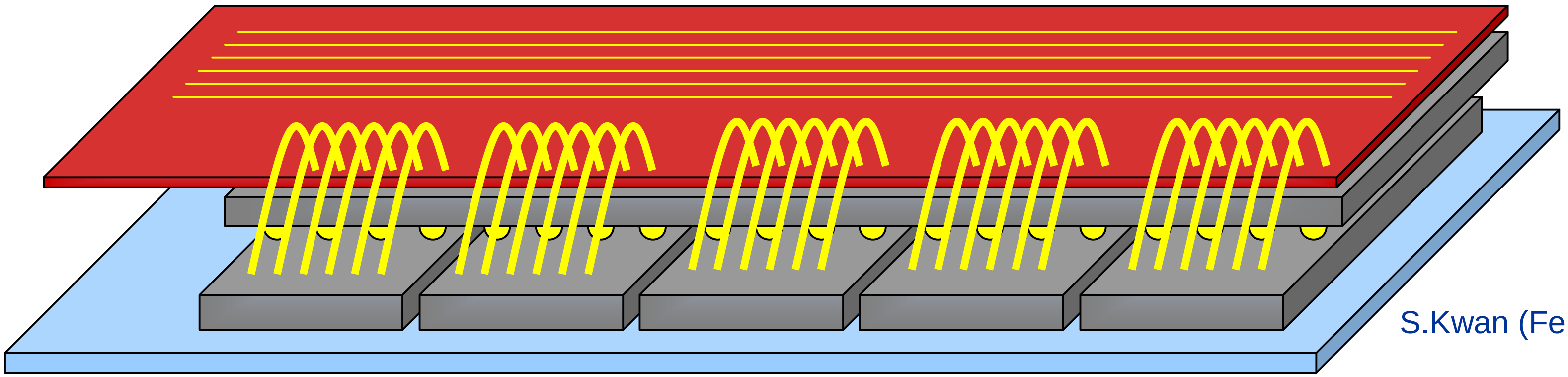
Prototype development at BNL

- 80 ? m x 3 cm strips
  (80 ? m x 1 mm
  effective strip size)
- 4.6º stereo
- Readout on both sides
- 2x 375 strips
- 1500 channels

Tests this summer/fall



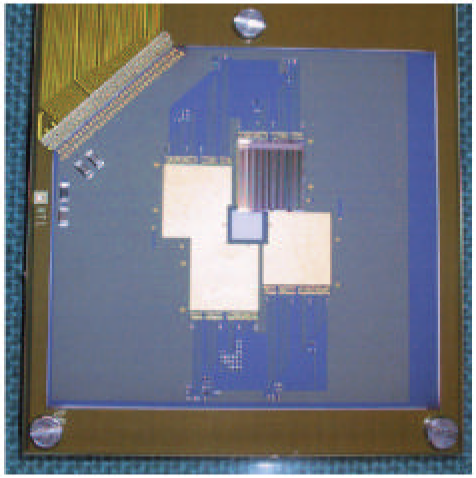
Hybrid Silicon Pixels



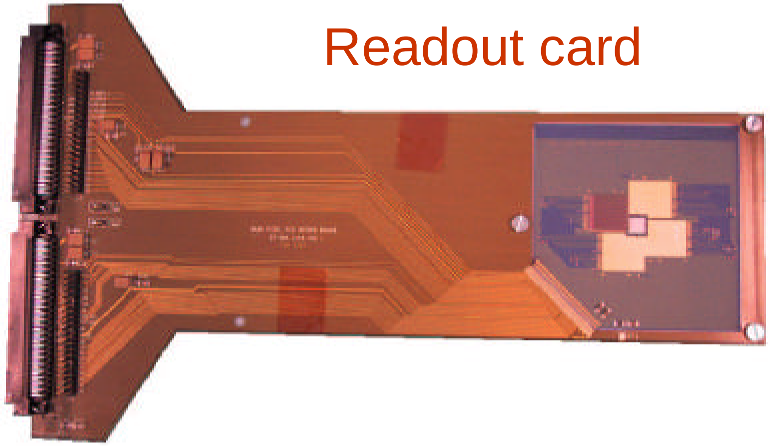
S.Kwan (Fermilab)

- **Sensor layer and readout layer are separate**
  (=> 2 layers of silicon per detector ; must be thin)
- **Sensor and readout are bump bonded together**
- **Evaluate development effort presently going on for NA60/ALICE at CERN**

NA60/ALICE Hybrid Pixels



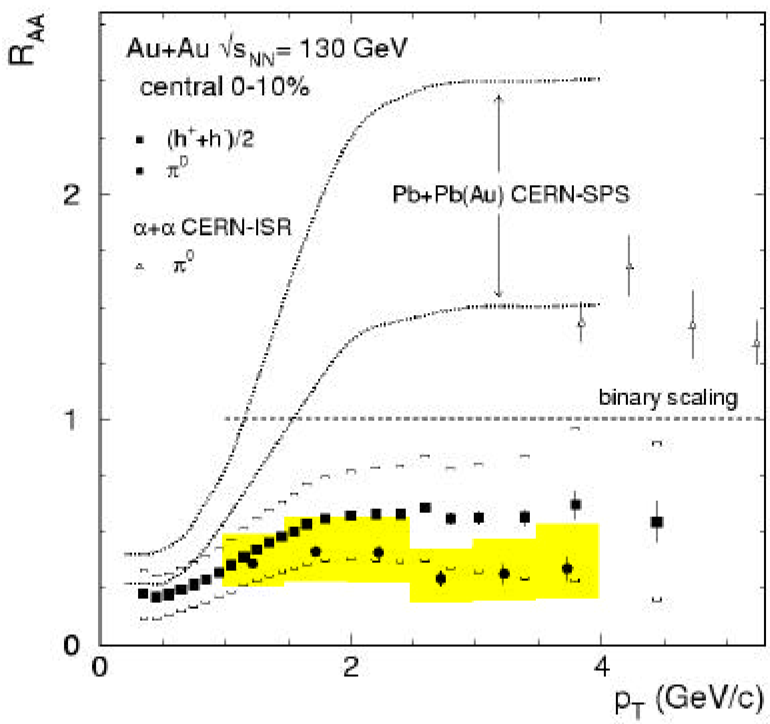
4X sensor
+ readout
chips

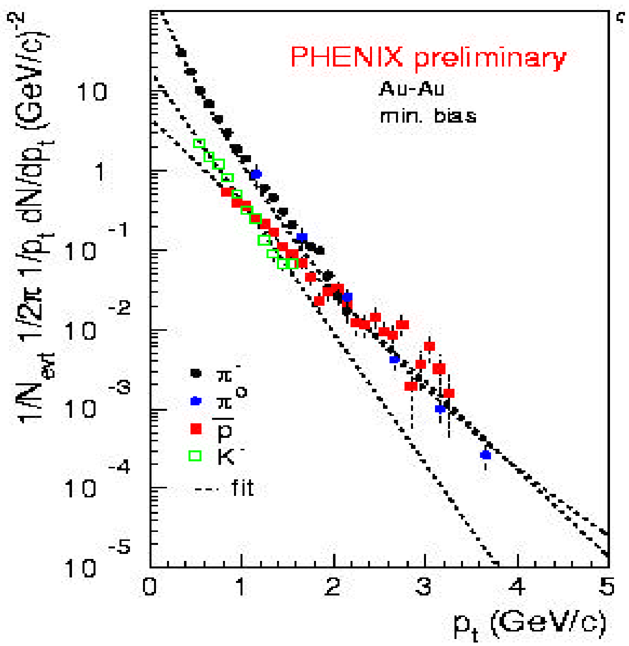


Readout card

- **Sensor layers manufactured at BNL (Instrumentation Divison)**
- **Readout Chip produced by joint NA60/ALICE collaboration**
- **PHENIX + RIKEN collaborators (2 postdocs) presently involved with beam test in NA60 to study performance**
- **Setting up test station at BNL to evaluate compatibility of NA60 chip with PHENIX readout and DAQ**

Enhanced High P_T Physics





Study flavor dependence of jet quenching (tag with *identified* high p_T particle)

Important to extend spectra of identified charged particles out to as high p_T as possible

Extended PID with Aerogel

		Pion-Kaon separation	Kaon-Proton separation
TOF	? ~100 ps	0 - 2.5	0 - 5
RICH	n=1.00044 ?th~34	5 - 17	17 -
Aerogel	n=1.007 ?th~8.5	1 - 5	5 - 9

Y. Miake

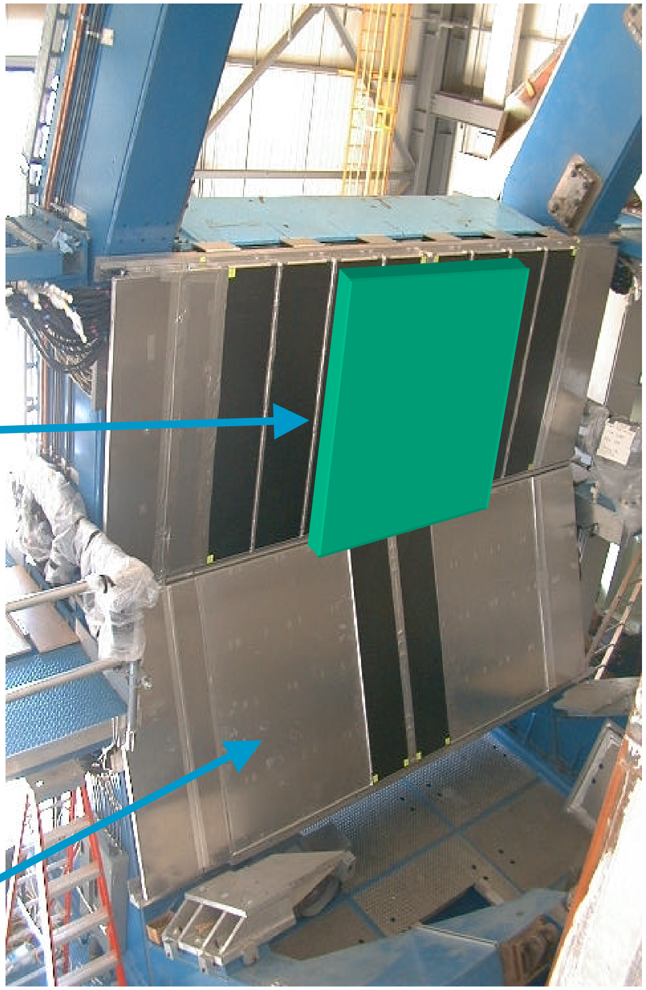
Aerogel together with TOF can extend the PID capability up to ~ 10 GeV/c

Aerogel Detector

Proposal by Tsukuba Group to install 400 liters of Aerogel, segemented into 300 modules

Shown on PHENIX East ARM over TOF

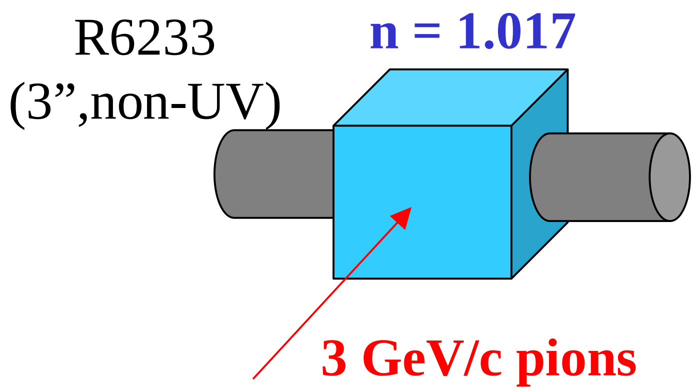
Would most likely go on West Arm between PC2 and PC3 (no TEC/TRD)



TOF panel
0.5 x 2.0 m

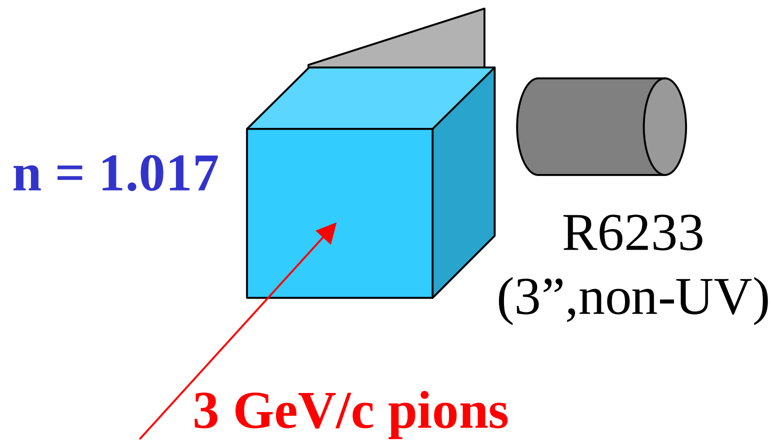
Two Detector Concepts

Belle Type



Reflector	***PMT1 (p.e.)***	***PMT2 (p.e.)***	***Total (p.e.)***
Goretex	12	13	25
Millipole	9	10	19
Tyvek	8	8	16
Black Paper	2	3	5

Mirror Type



Mirror Shape	Npe
Flat (Tyvek)	9
Parabora (Tyvek)	9
Parabora (Goretex)	14

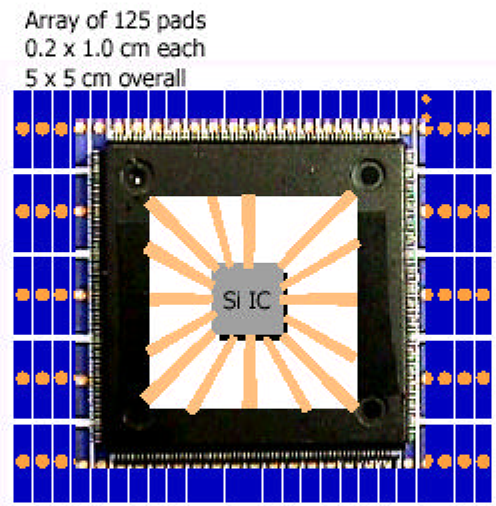
Electronics Development for PHENIX Upgrades

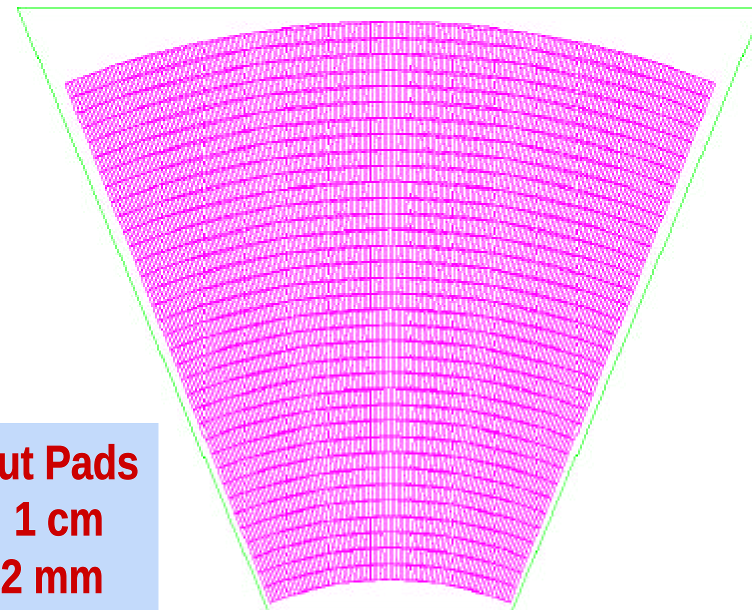
- Need to develop new readout electronics for silicon utilizing existing readout chips and integrate into the PHENIX DAQ

- A significant effort will be required to develop new readout electronics for the mini TPC
  - new front end ASIC design
  - new FEM which will include zero suppression (same for silicon)

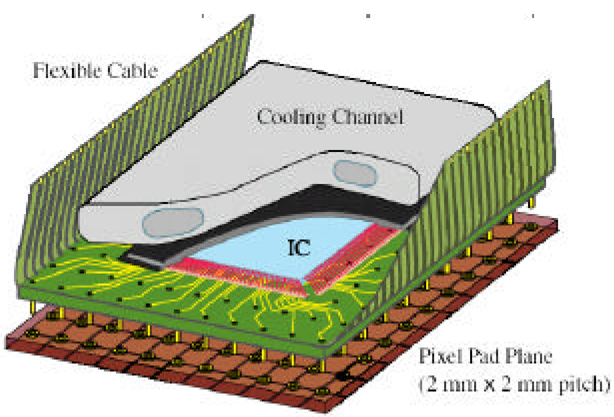
- Electronics for the HBD may be simpler, but will also require a significant amount of development
  - lower noise due to smaller primary signal, larger pads,...
  - must be low mass (part will sit in the PHENIX acceptance)

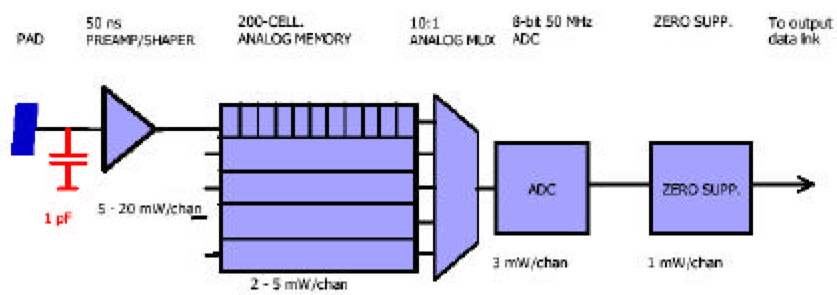
TPC Readout Electronics





Readout Pads
DR ~ 1 cm
f ~ 2 mm





P.O'Connor

Present PHENIX DAQ Capabilities

RHIC luminosity reached in Run 2

Au-Au L ~ 2×10^{26} $cm^{-2}s^{-1}$ (blue book - briefly)

p-p L ~ 1×10^{30} $cm^{-2}s^{-1}$ (~ 10% blue book, 1% spin design)

Trigger rates:

- Ran with up to 1.2 kHz rate in Run 2
- Expect possible raw trigger rates of ~ 11 kHz (HI) and 800 kHz (pp) in Run 3
- PHENIX should be able to take ~ 8 kHz (limited mainly by multiplexing of FEMs)
- Maximum Level-1 trigger accept rate = 25kHz (requires demultiplexing)

Data volume:	Au-Au	pp
Event size	~ 150-200 kB	~ 50 kB

Level 2 Trigger (Event Builder): Au+Au: 150kB x 8 kHz = 1200 MB/s

Archiving rate at RCF ~ 40MB/s => Need factor ~ 30 rejection at Level 2

DAQ and Trigger Upgrades

New physics requires high luminosity
New detectors produce large data volumes (silicon, TPC)

Expected luminosity upgrades at RHIC (RHIC-II)

Au-Au L ~ 8 x 10^{27} $cm^{-2}s^{-1}$ (x40)
O-O L ~ 1.6 x 10^{29} $cm^{-2}s^{-1}$
p-p L ~ 4 x 10^{32} $cm^{-2}s^{-1}$ (possibly -> 4 x 10^{33} $cm^{-2}s^{-1}$)

Changes and Improvements to DAQ

- **Zero suppression in FEMs**
- **Upgraded DCM modules**
- **Gigabit ethernet to replace ATMs**
- **Level 3 trigger**
- **Up to 100 MB/s data logging rate at RCF**
  (similar to ATLAS + CMS; ALICE ~ 1250 MB/s)

Time Scale and Cost

2002 - Completion of Baseline Detector

Install North Muon Spectrometer
Upgrade TEC to TRD

2003-2004

Silicon strip detectors
Prototype silicon pixel detector
Prototype HBD (upgradable to TPC)
Prototype aerogel detector

2005-2007

Complete silicon pixel detectors
Complete TPC/HBD
Complete aerogel detector

R&D 2002-2005

- presently supported by various institutional funds (LDRDs,RIKEN)
- requires ~ 3-4 $M over 3-4 yrs
- needs DOE funding to continue

Construction 2004-2007

- Staged approach, with detectors requiring less R&D to be implemented first
- NSAC plan shows $80M in RHIC II detector upgrades over 7 years starting in FY05